Potential for Carbon Sequestration and Greenhouse Gas Mitigation in California Soils: A Scoping Study.

Presented by

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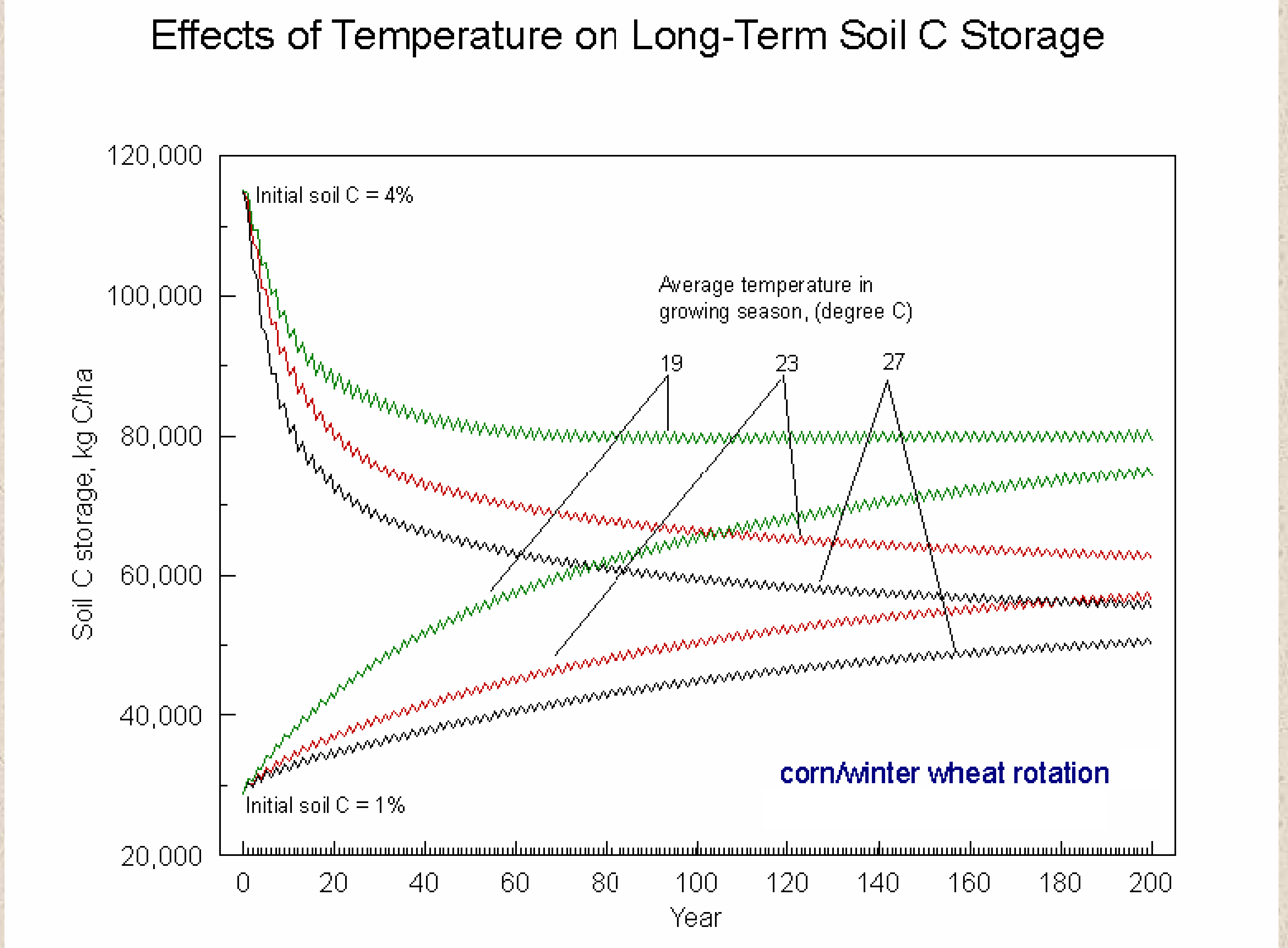
Presented at CEC's First Annual Climate Change Conference, Sacramento, CA, June 2004

Role of Process-based Models for Emission Inventories, Policy Analyses, and Mitigation Studies

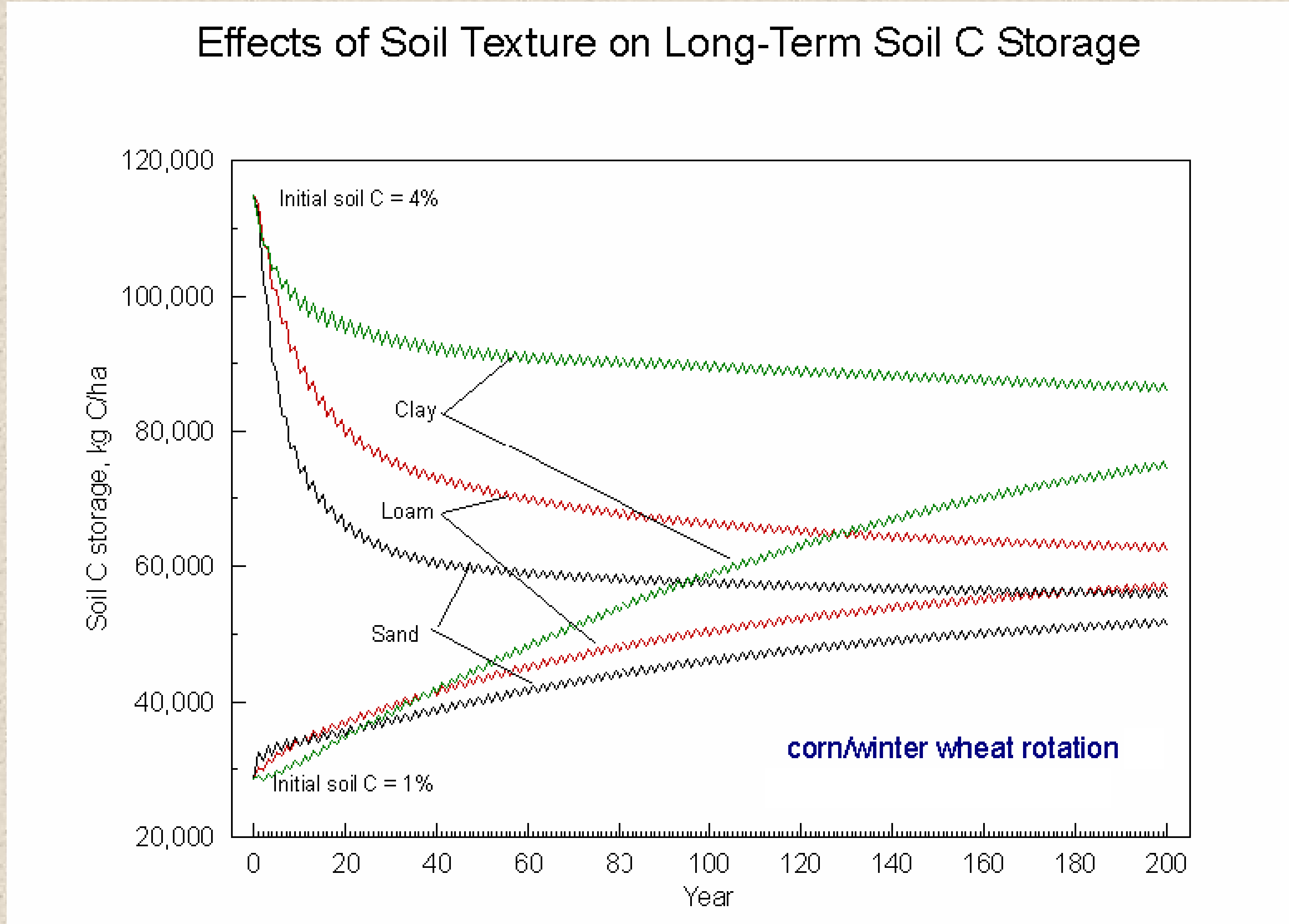
- Spatial and temporal variability in
  - Climate
  - Soils
  - Management Impacts
- Long-term impacts? Decade? Century?
- C and N coupling: Effect on GWP!

Must move beyond the emission factor approaches!

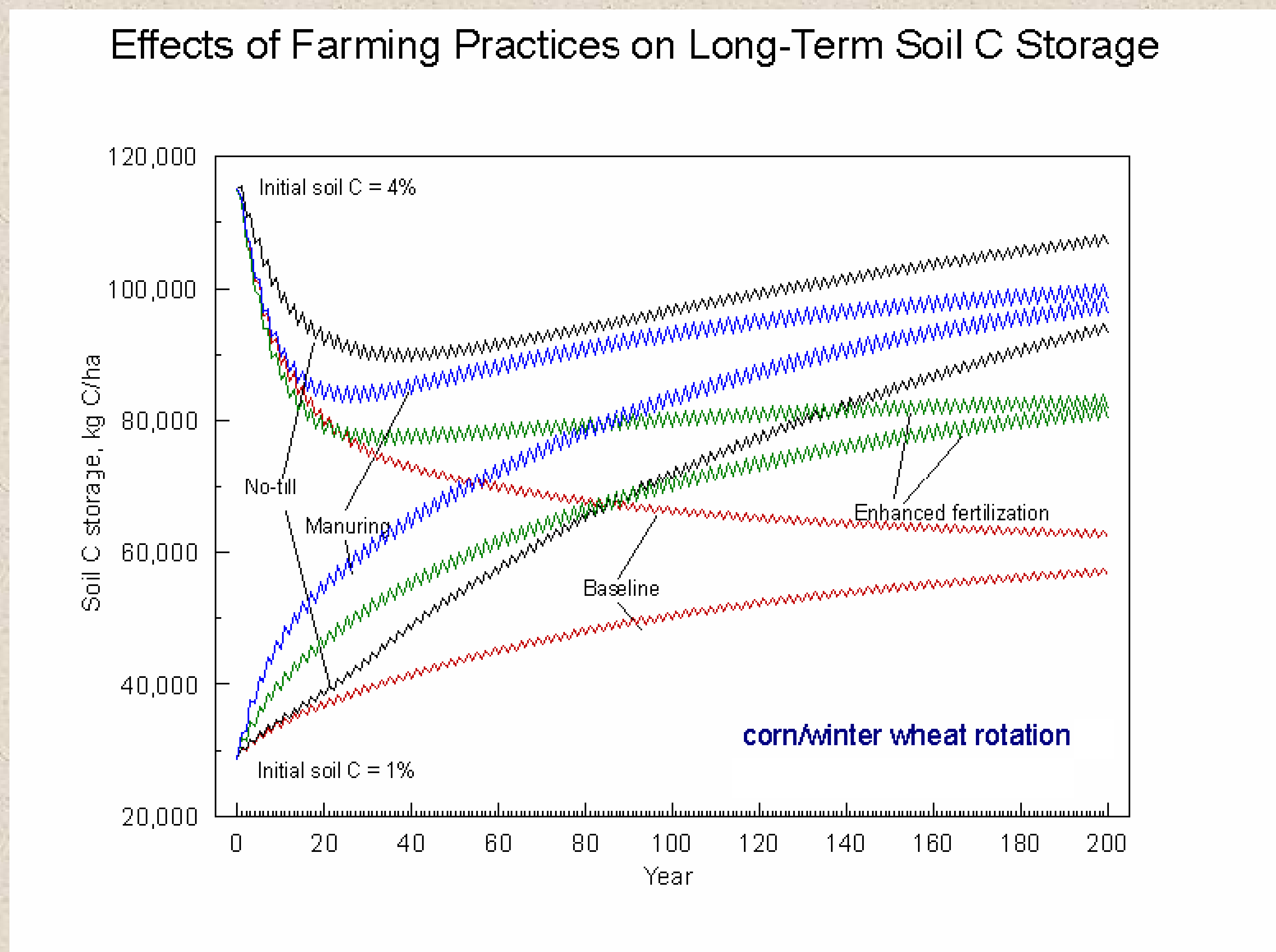
Climate Impacts



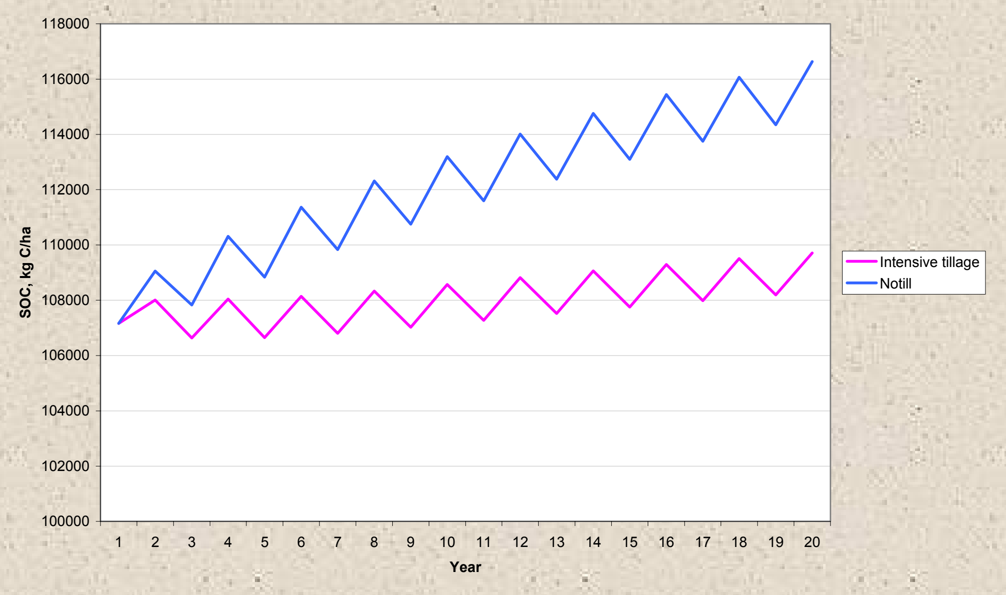
Site Variability: Soil Impacts

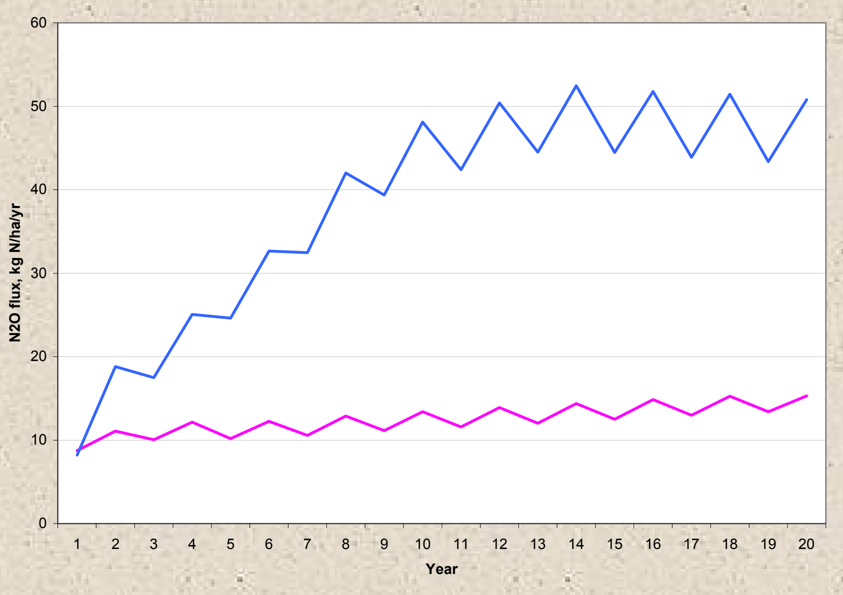


Management Impacts



Carbon Sequestration and Trace Gas Emissions



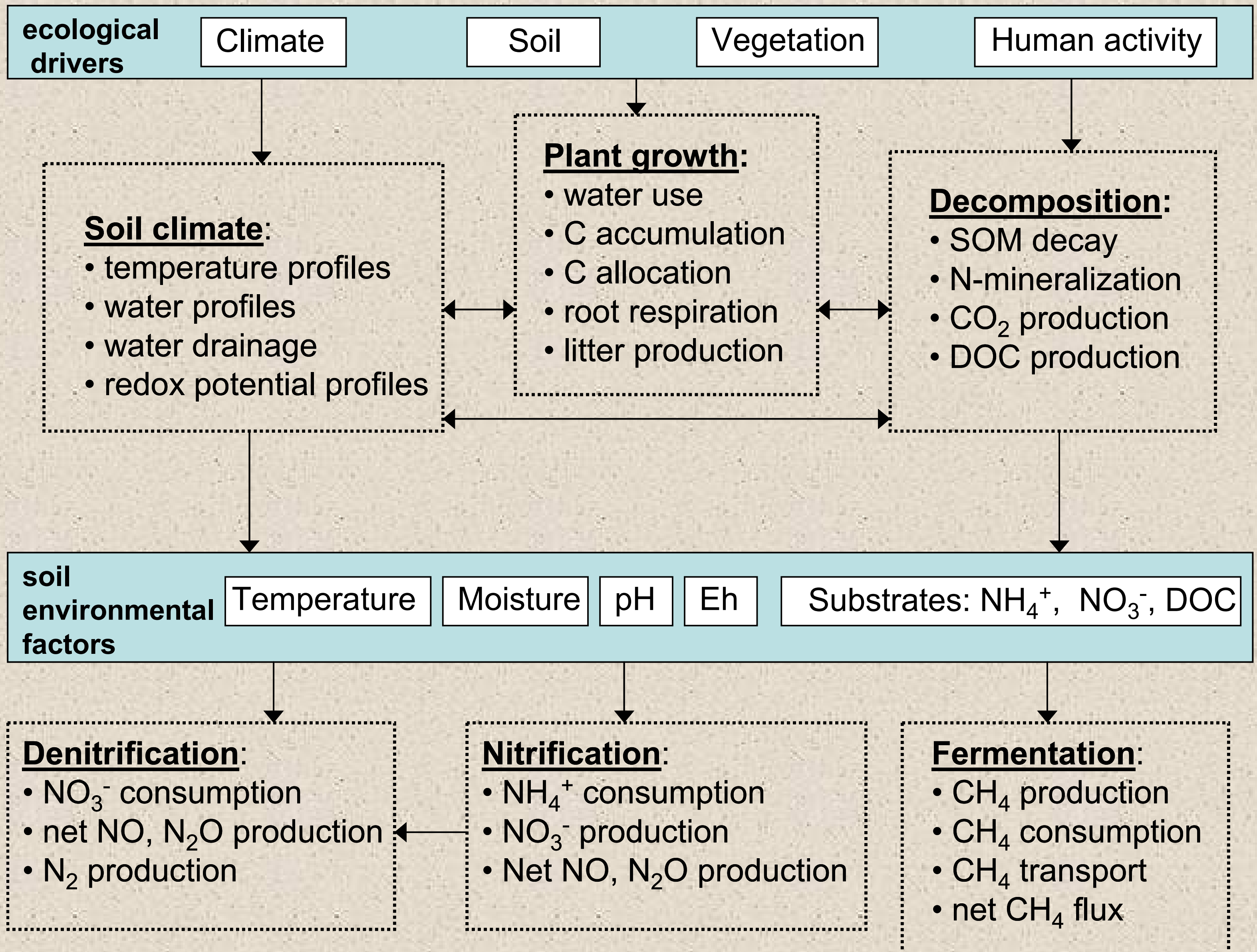


DNDC modeled changes in soil organic carbon content (SOC) and nitrous oxide (N2O) emissions from a corn-soybean rotation under two different management systems. Initial soil conditions were set to be identical with the same nominal climate conditions. It is clear that a constant or even site specific emission factor for N2O would not capture the temporal dynamic of emissions.

Objective of Scoping Study

- *Use the Denitrification-Decomposition, or DNDC, process-based soil biogeochemical model to simulate recent SOC dynamics and N_2O emissions at the county scale for California, and*
- *Make recommendations for more detailed studies on carbon sequestration and N_2O emissions under a wide scope of alternative management scenarios.*

DNDC Model

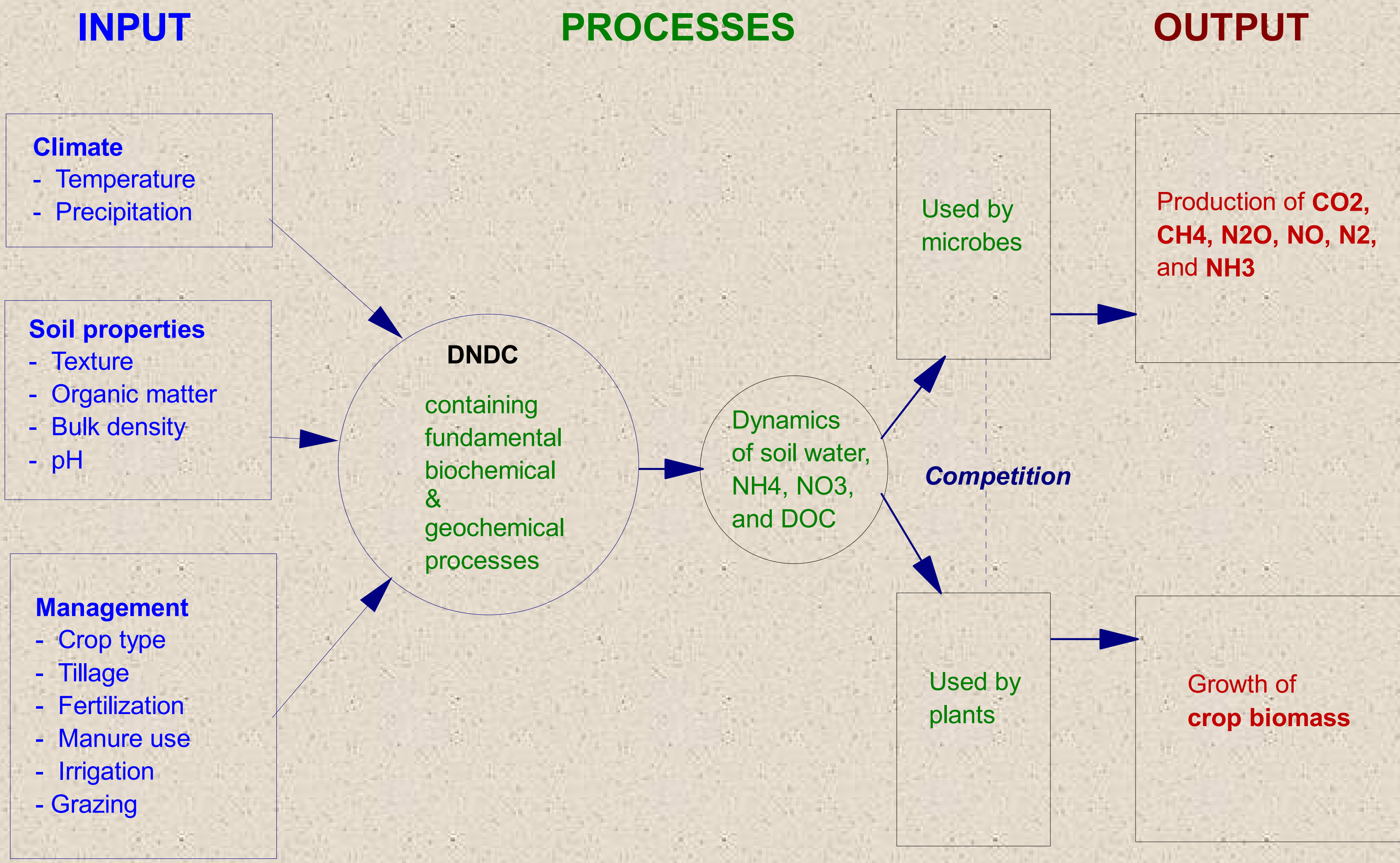


ecological drivers
Climate
Soil
Vegetation
Human activity
Soil climate:
• temperature profiles
• water profiles
• water drainage
• redox potential profiles
Plant growth:
• water use
• C accumulation
• C allocation
• root respiration
• litter production
Decomposition:
• SOM decay
• N-mineralization
• CO_2 production
• DOC production
soil environmental factors
Temperature
Moisture
pH
Eh
Substrates: NH_4^+, NO_3^-, DOC
Denitrification:
• NO_3^- consumption
• net NO, N_2O production
• N_2 production
Nitrification:
• NH_4^+ consumption
• NO_3^- production
• Net NO, N_2O production
Fermentation:
• CH_4 production
• CH_4 consumption
• CH_4 transport
• net CH_4 flux

How DNDC Links Management to C and N Dynamics:

Elemental cycling	Biochemical & geochemical reactions	Environmental factors	Ecological drivers
Transport and transformation of chemical elements	Mechanical movement Dissolution / crystallization Combination / decomposition Oxidation / reduction Adsorption / desorption Complexation / decomplexation Assimilation / dissimilation	Gravity Radiation Temperature Moisture Eh pH Substrate concentration gradient	Climate Soil Vegetation Anthropogenic activity

DNDC Links Ecological Drivers to Crop Yield/Trace Gas Emission



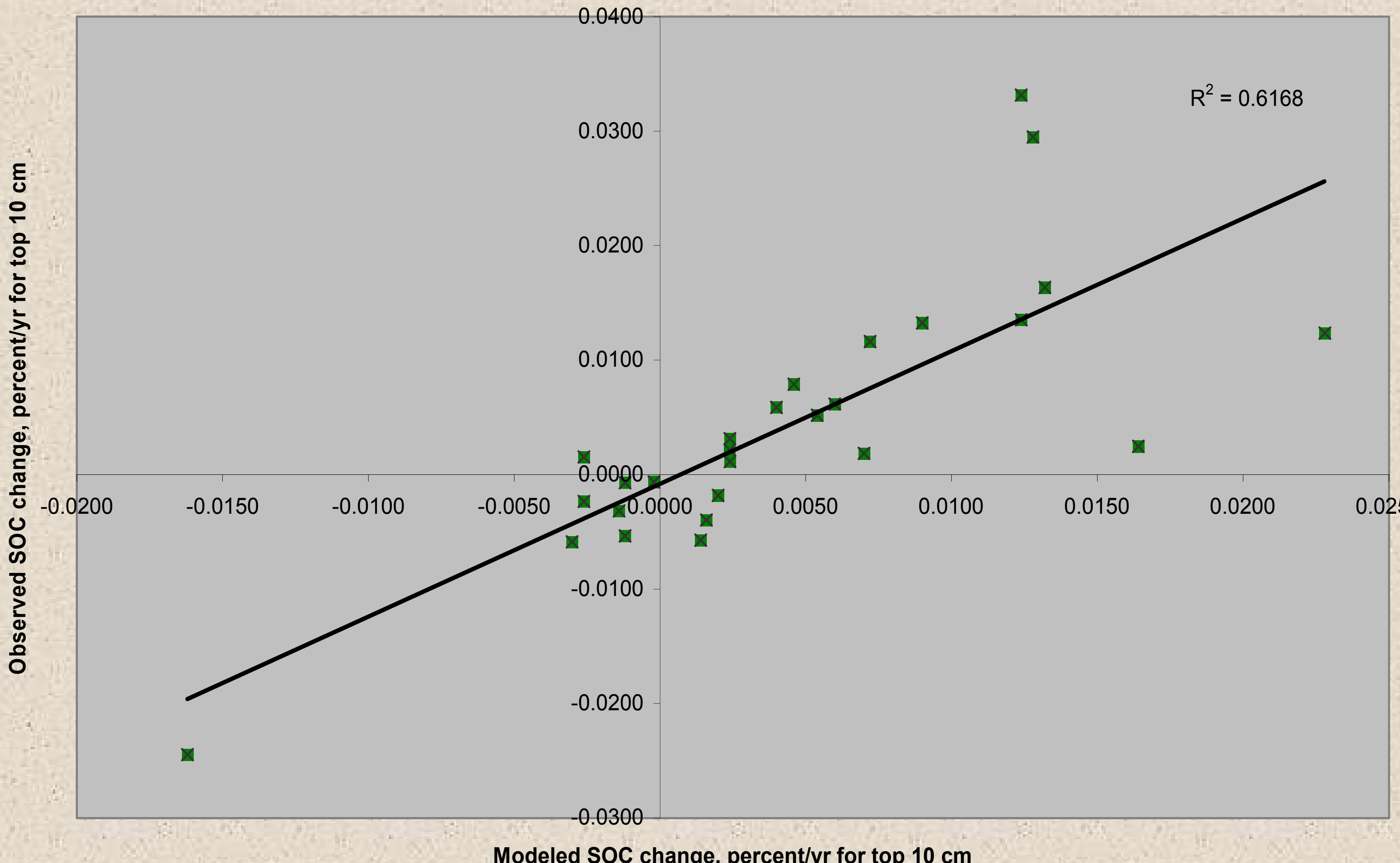
Climate and Management Scenarios

- **1983 Climate:** Since our baseline year 1997 was a relatively hot and dry year for California, we ran a scenario using climate data for 1983, which was relatively cool and wet year.
- **Alternative litter incorporation**: We varied our assumption regarding the amount of residue left on site from our baseline assumption with 50% to 0% to 90% of aboveground litter incorporation.
- **Alternative irrigation**: Our baseline scenario had the irrigation index set at 1, signifying that crops were irrigated to exactly meet agronomic demand. We ran a scenario where crops were over irrigated by 10% by setting our irrigation index at 1.1.
- **Alternative manure amendment**: Our baseline scenario had no manure amendments. For this scenario we applied 2000 kg C/ha with 90% residue incorporation for all of crops in all counties.
- **Multiyear climate**: 18 years of climate data (1980 through 1997) for two counties (Fresno and Sutter), with 90% residue incorporation.

DNDC Validation

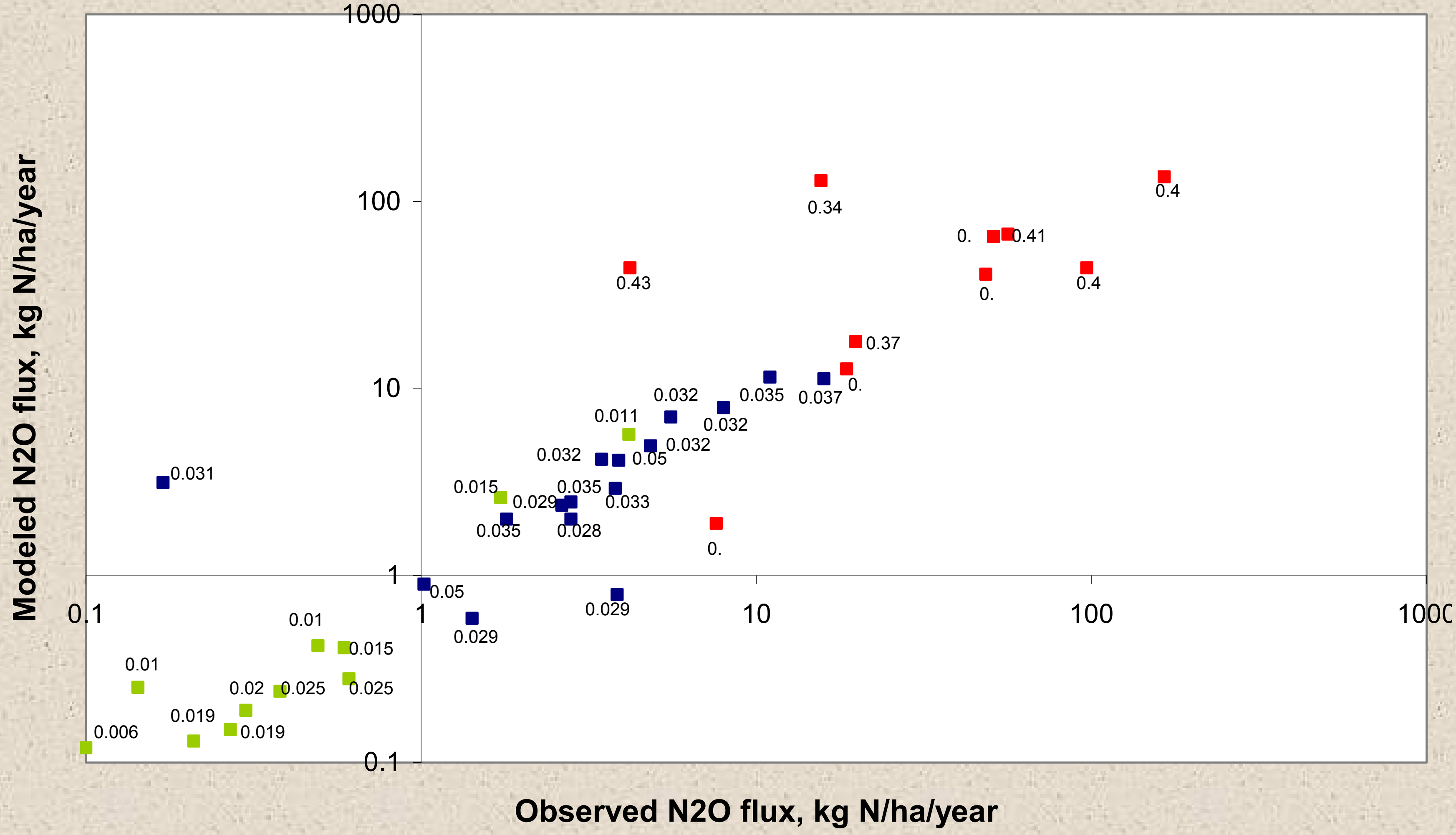
- Approach:
  - Site scale validation
  - Independent researchers
  - Sites have covered wide range of agro-ecosystems, soils and climate conditions
  - California: preliminary SOC validation, additional validation analyses is on going …
- Regional Applications: scaling site to region
  - Uncertainty analyses based on variability of input parameters: Most Sensitive Factor (MSF) and Monte Carlo Analyses

Observed and DNDC-modeled average annual SOC changes at 27 sites in agricultural lands in Colusa, Fresno and Glenn Counties, CA during 1949-1999



Field observations were provided by Dr. M. Singer (DeClerck et al. 2003).

Observed and DNDC-Modeled N2O Fluxes from Agricultural Soils in the U.S., Canada, the U.K., Germany, New Zealand, China, Japan, and Costa Rica



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County Level Input Data

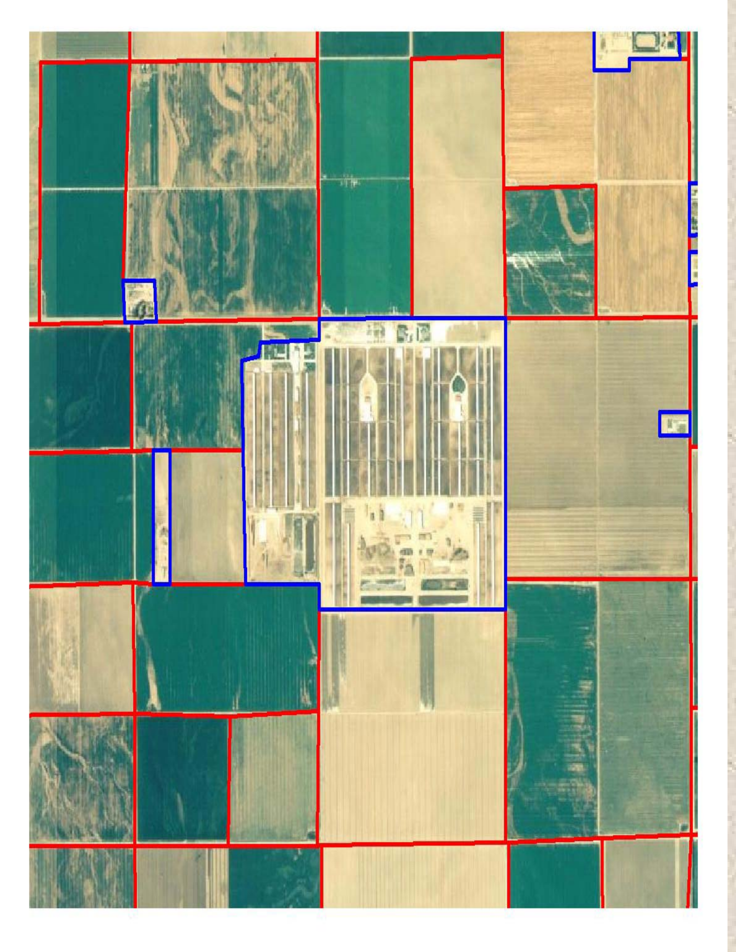
- Climate Data (daily Tmin, Tmax, Precip)
- Crop type and areas by county
- Soils (carbon, pH, texture, and bulk density)
- Management Practices (fertilizer, tillage, irrigation, planting/harvesting dates, etc)
- Scenarios for Carbon Sequestration

Climate Data Inputs:

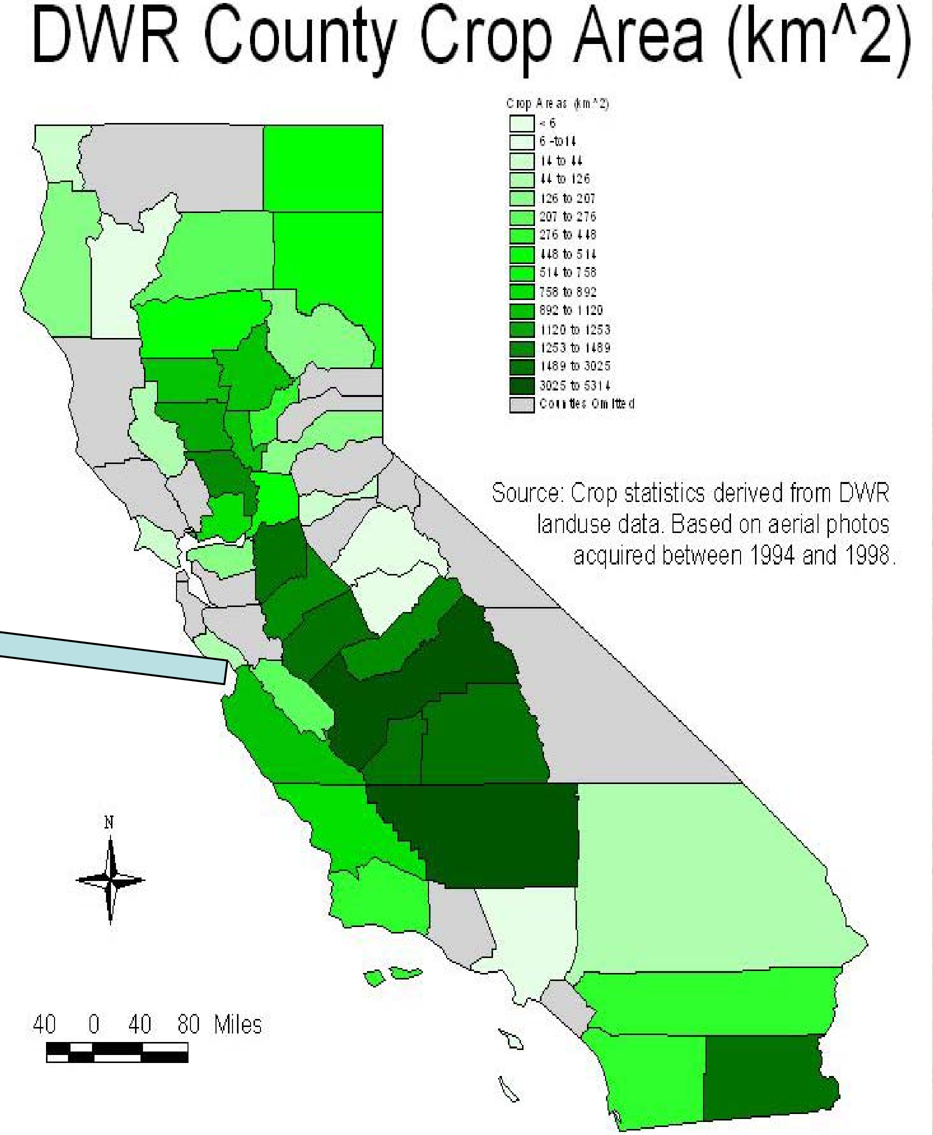
- Minimum Needs: Daily *Tmax*, *Tmin*, Precip
- Sources: Station data: NCDC and CIMIS, gridded DAYMET (NCAR/U Mont) data
- DAYMET:
  - Produces daily temp, precipitation, humidity and radiation based on station data
  - Performs interpolation based on "spatial convolution of a truncated Gaussian filter"
- Analysis: Using 1997 and 1983 daily DAYMET data for station nearest County centroid.

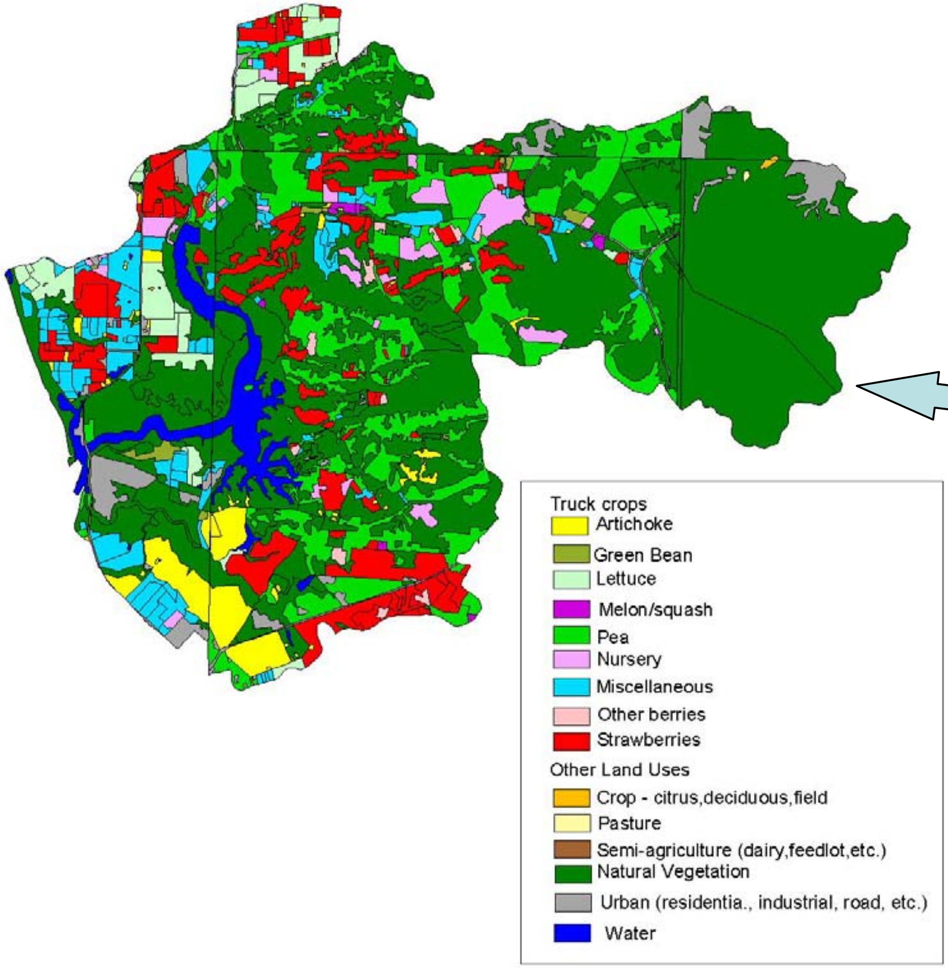
County Agricultural Data

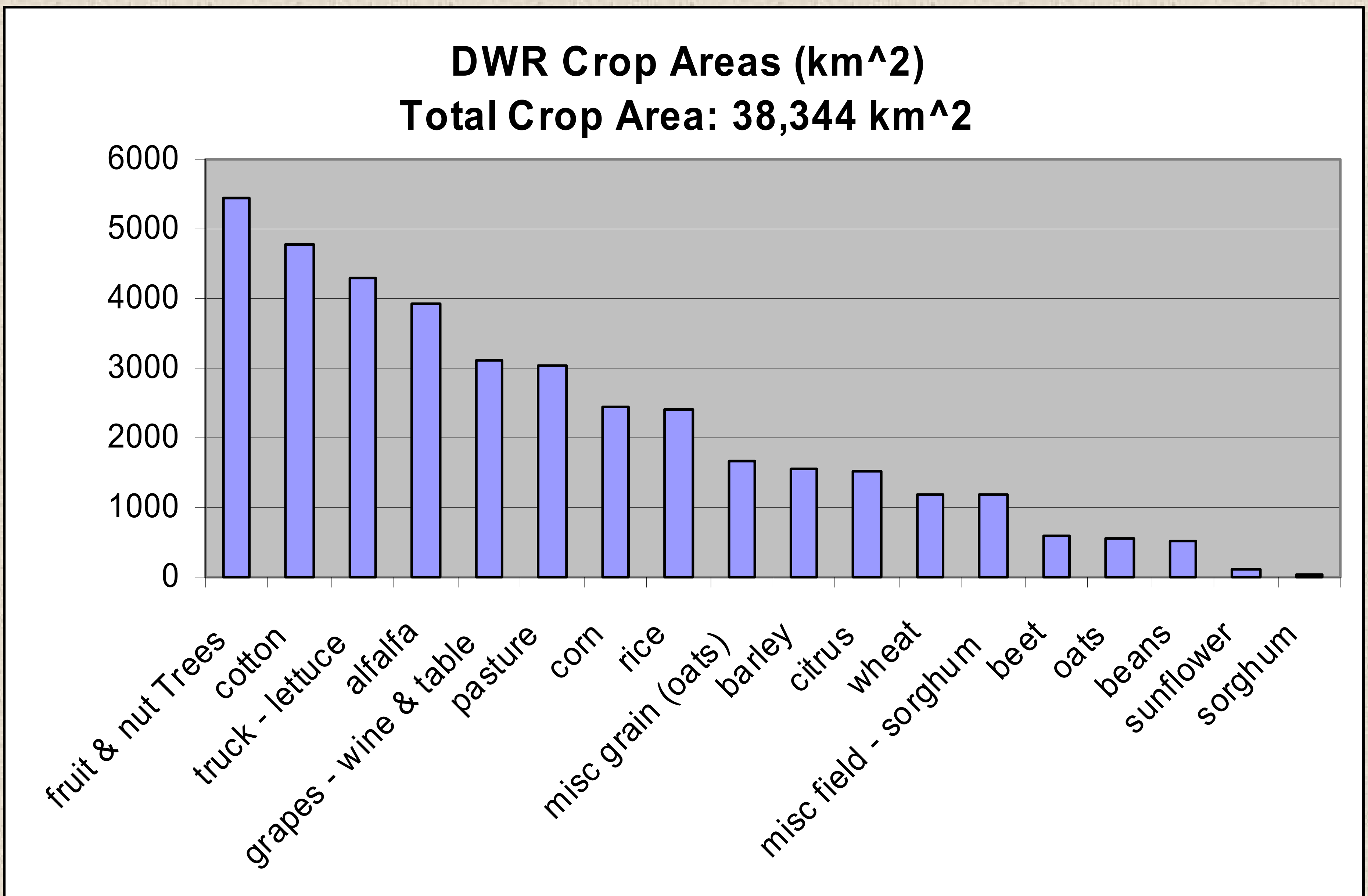
- Various Sources of California data: County Commissioners Reports, FRAP (Fire Resource & Assessment Program, CDF), NASS, DWR → All have pluses and minuses!
- Used DWR mid-1990s data:
  - Sub-county spatial resolution
  - Based on Aerial Photos coupled with field surveys
  - Total crop area: 38,344km^2



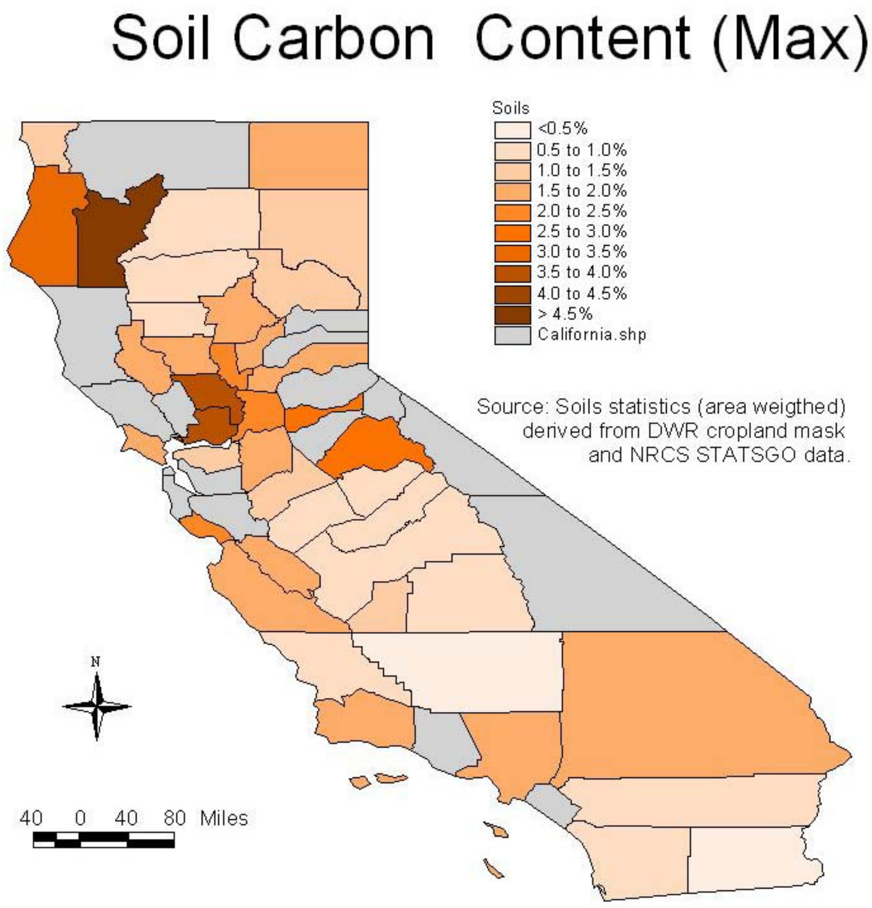
GIS Database

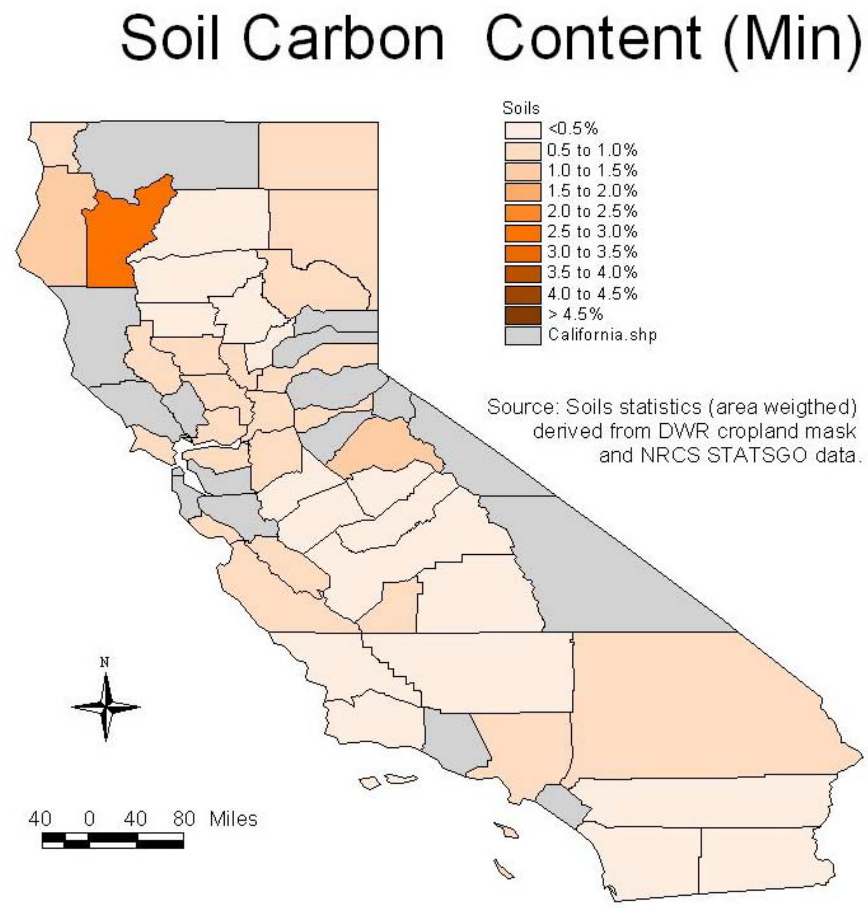





DWR Crop Areas (km^2)
Total Crop Area: 38,344 km^2
6000
5000
4000
3000
2000
1000
0
fruit & nut Trees
cotton
truck - lettuce
alfalfa
grapes - wine & table
pasture
corn
rice
misc grain (oats)
barley
citrus
wheat
misc field - sorghum
beet
oats
beans
sunflower
sorghum

Soils Data: NRCS STATSGO





Management Data

- Compiled data on tillage practices, fertilizer use, planting and harvesting dates, and irrigation practices.
  - Sources: surveys (from CARB Fugitive Dust Study) and UCCE Crop Cost Studies

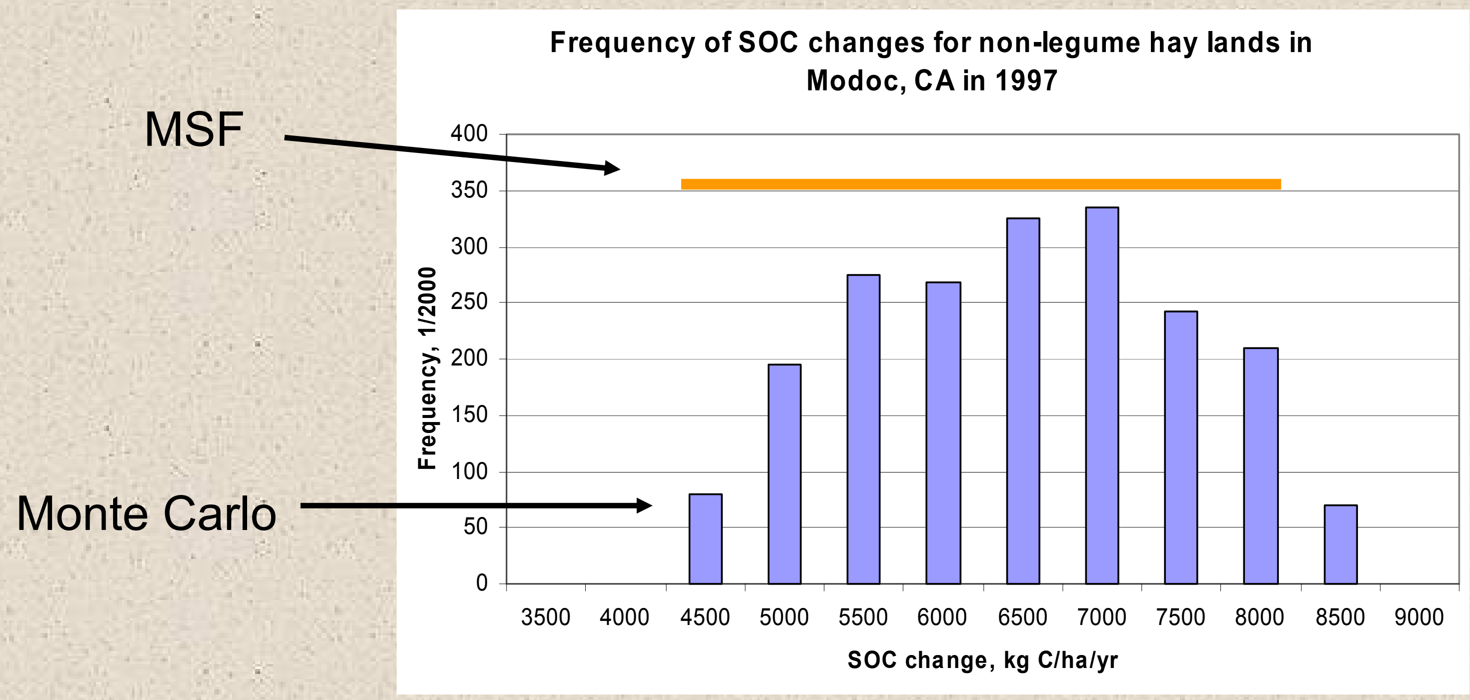
Crop	Total (kg N/ha)	Application Dates (with rate kg/ha)	Tillage Dates
Cotton	140	4/1 (100) and 6/1 (40)	3/1 and 12/1
Corn	140	4/1 (140)	1/15 and 12/1
Wheat	100	12/1 (30) and 2/1 (70)	8/5 and 10/15
Oats	100	6/1 (100)	3/1 and 12/1
Alfalfa	0	NA	1/5 and 11/1
Deciduous Fruit	110	4/1 (55) and 7/1 (55)	25-Dec
Rice	120	5/1 (120)	3/1, 4/1 and 11/1
Vineyards	70	3/1 (35) and 6/1 (35)	4/1 and 11/1
Lettuce	265	3/1 (165) and 6/1 (100)	1/15 and 11/1

Regional Applications of DNDC

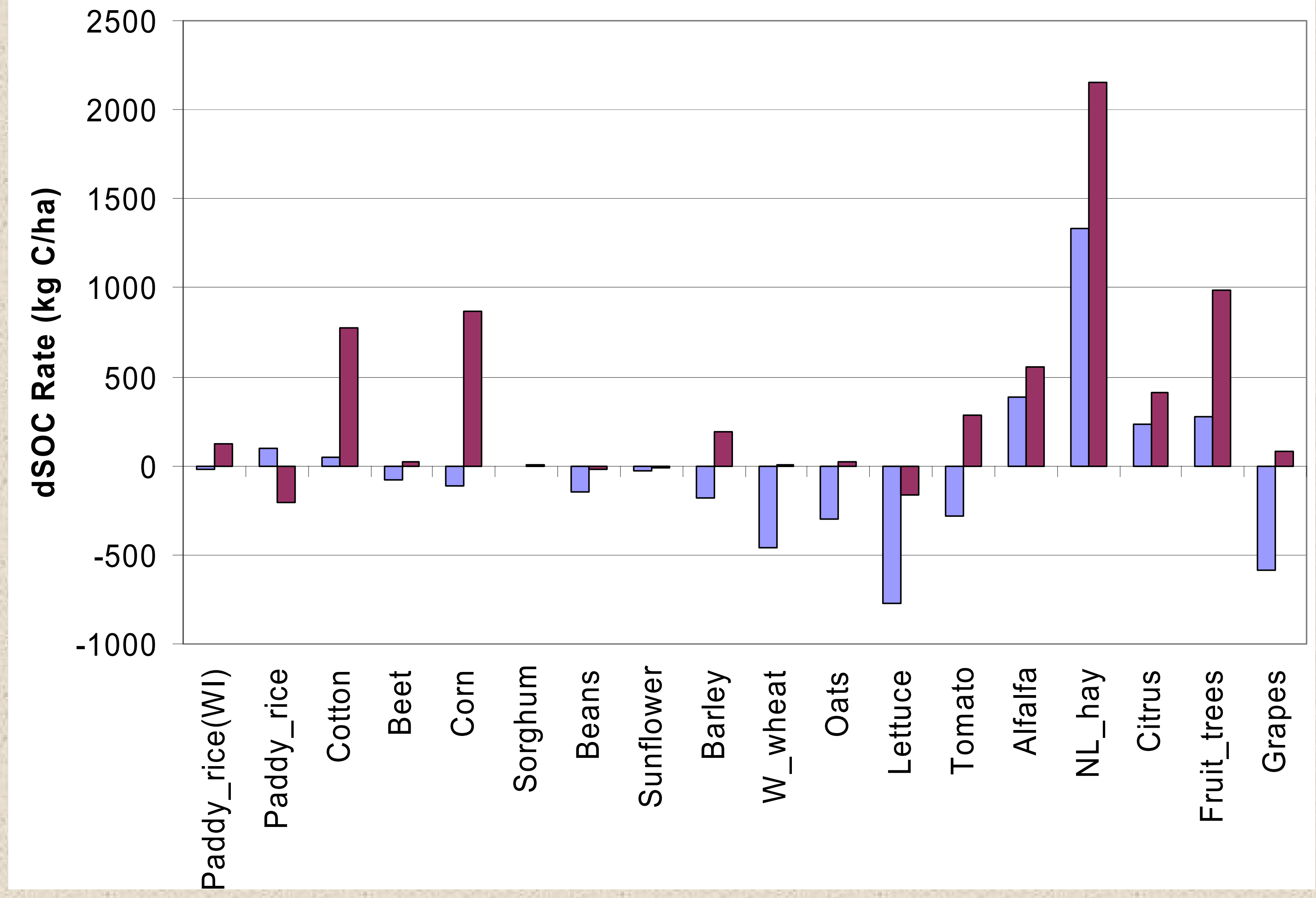
- Estimating uncertainties is a critical Issue in scaling site to region
  - Uncertainty analyses based on variability of input parameters: Most Sensitive Factor (MSF) and Monte Carlo Simulations
  - Outputs provided in ranges. (e.g. 3.5 to 5.4 kg N_2O/ha)

Results: Presented as Ranges

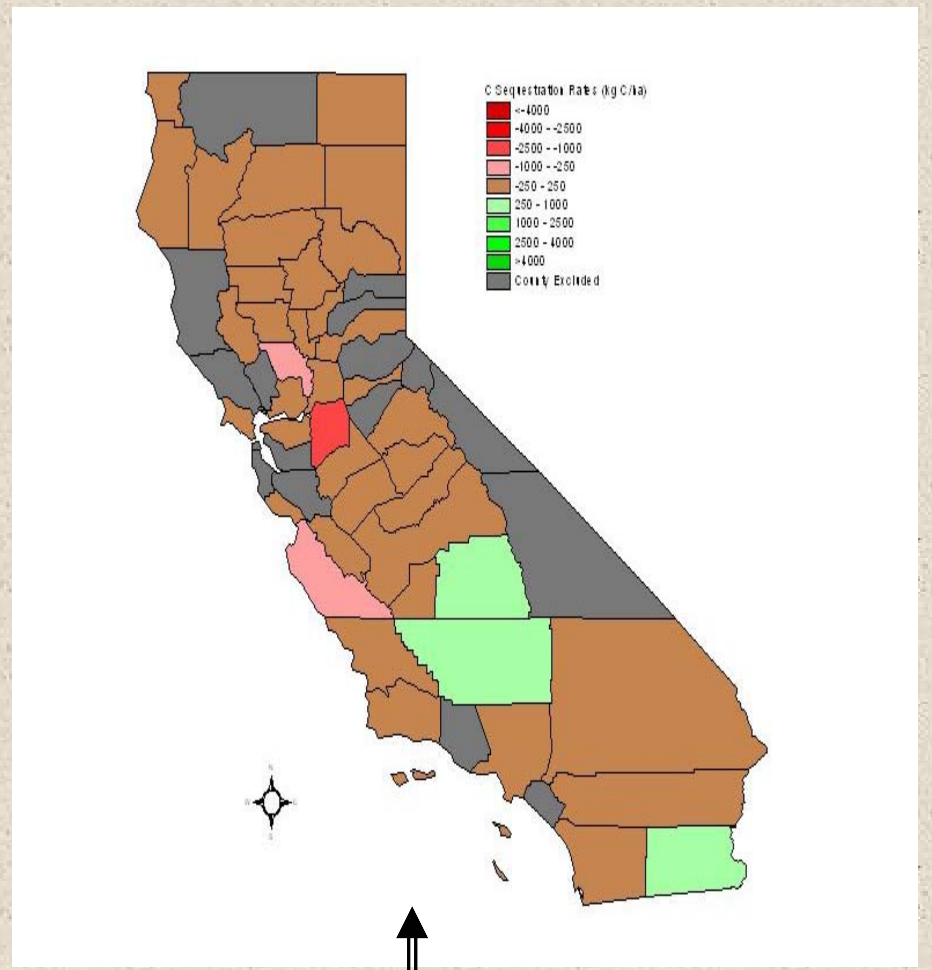
- In general, SOC dynamics and N2O emissions are most sensitive to the initial SOC content (relative to soil pH, texture, and bulk density)
- For each cropping system in each county, we run DNDC twice with the maximum and minimum SOC values, respectively. The two model runs will produce two results of SOC change (or N2O flux). The two flux values form a range, which we contend will, with a high probability, be wide enough to include the “real” flux.



Ranges in C Sequestration by crop type based on the max (blue) and min initial SOC (maroon)

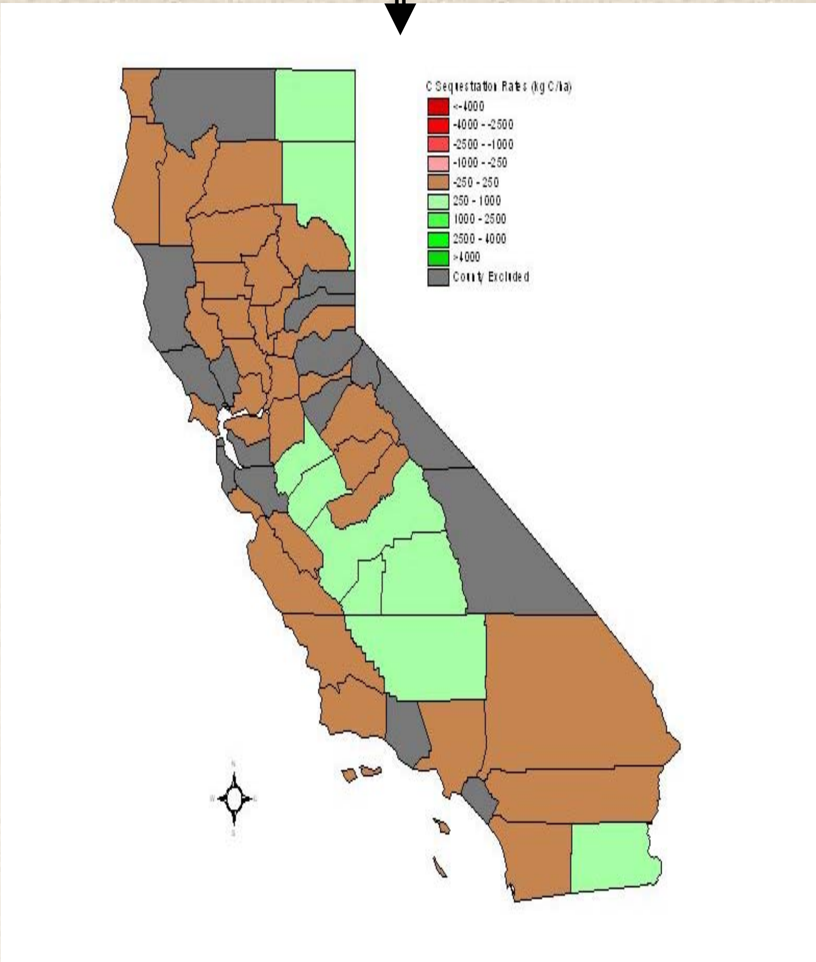


Carbon Sequestration Rates
Units: Tons C/ha

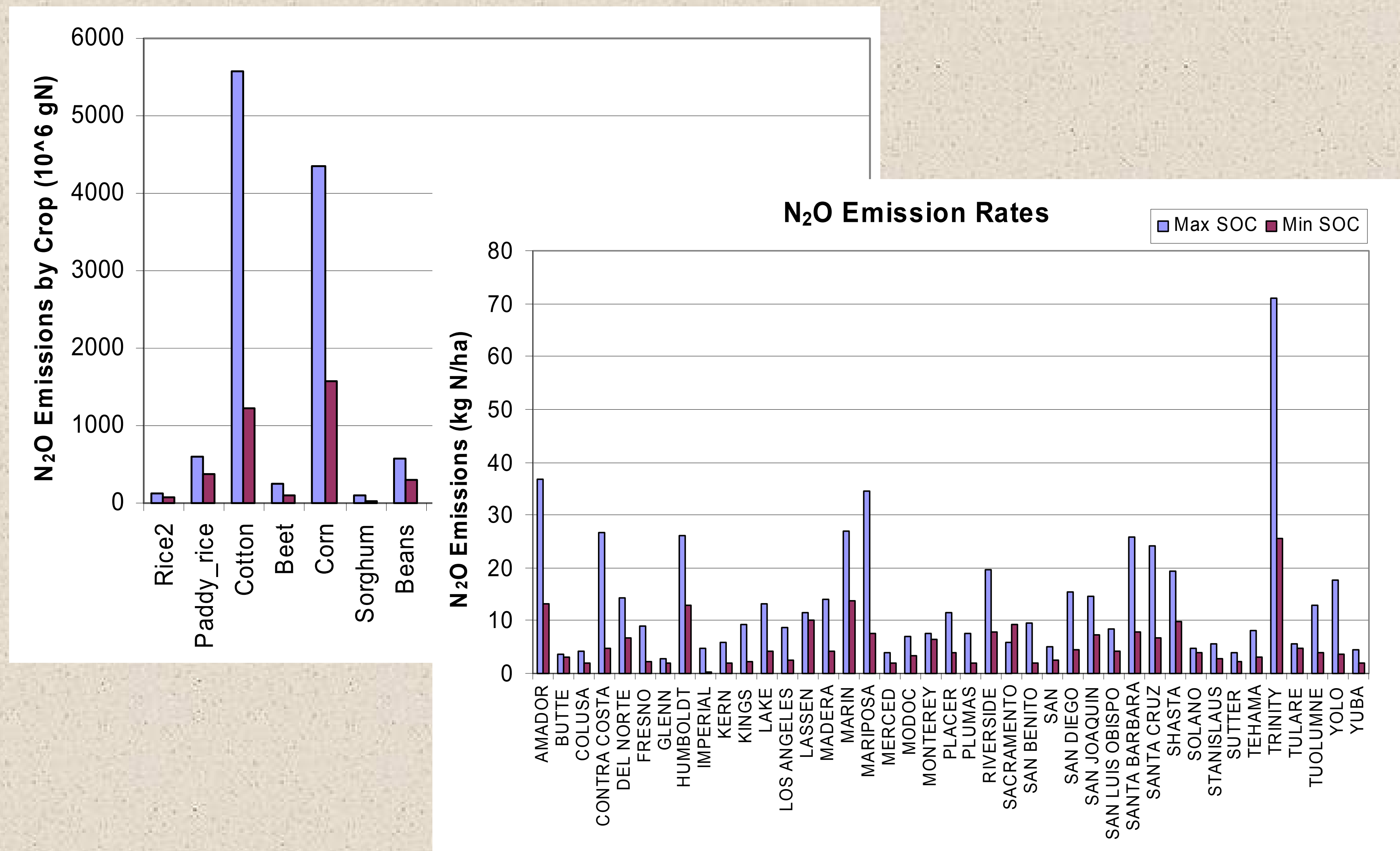


Upper Estimate

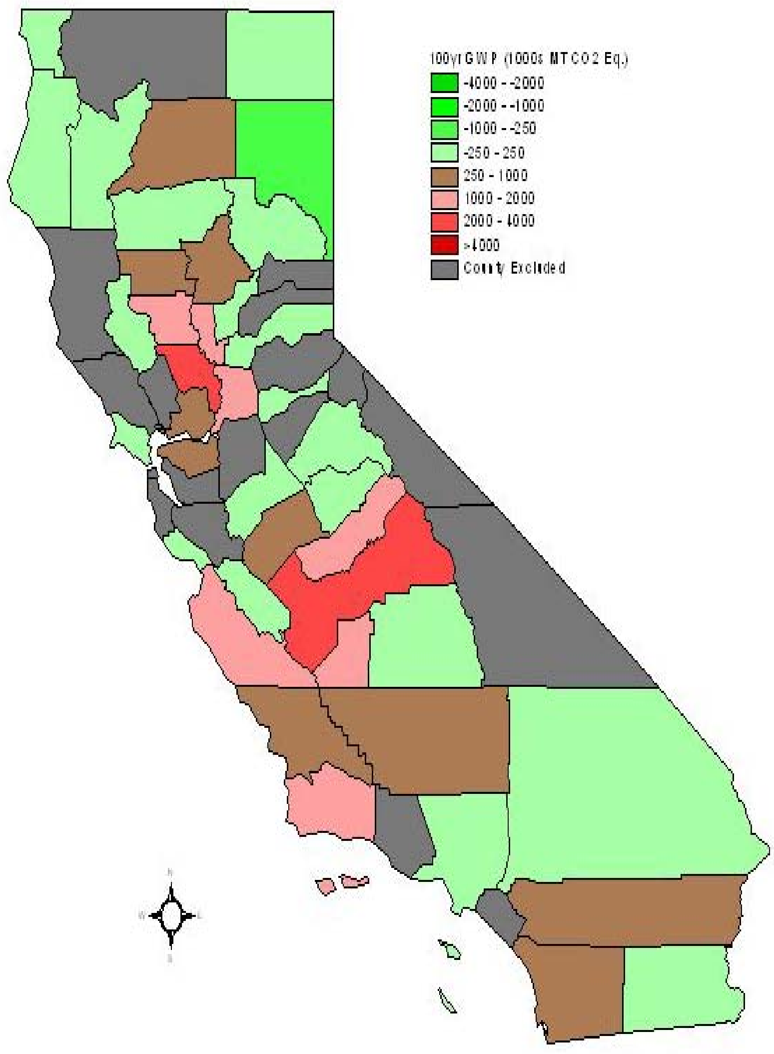
Lower Estimate

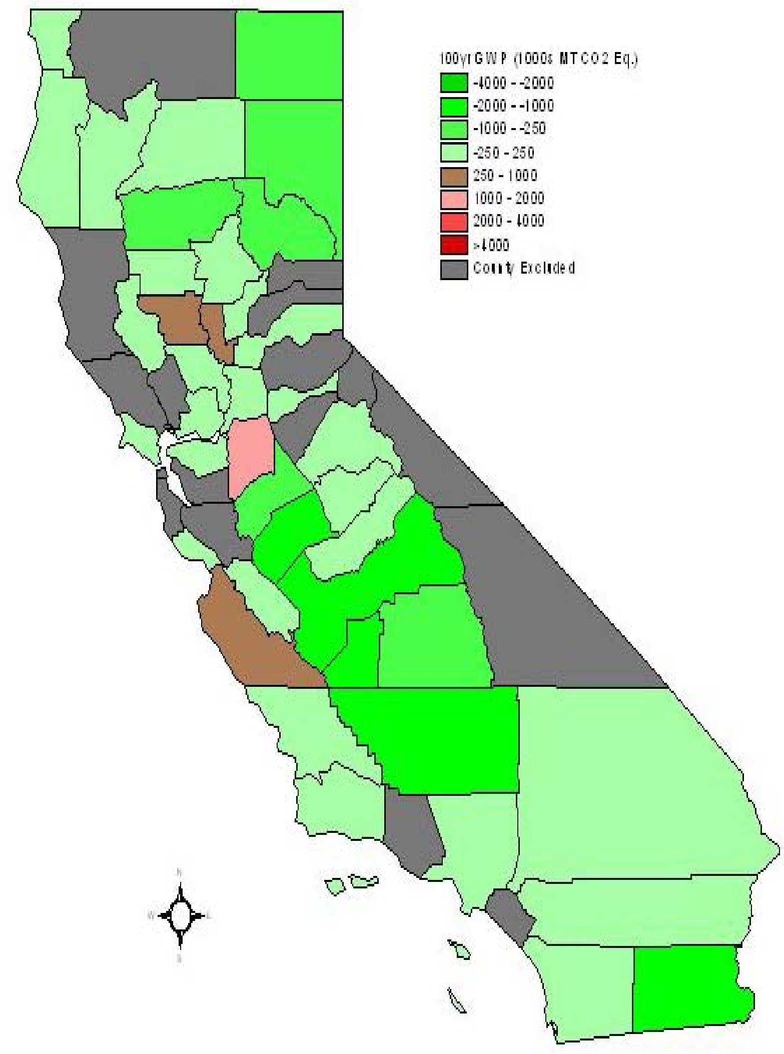


Nitrous Oxide Emissions



Net GWP: Baseline Scenario





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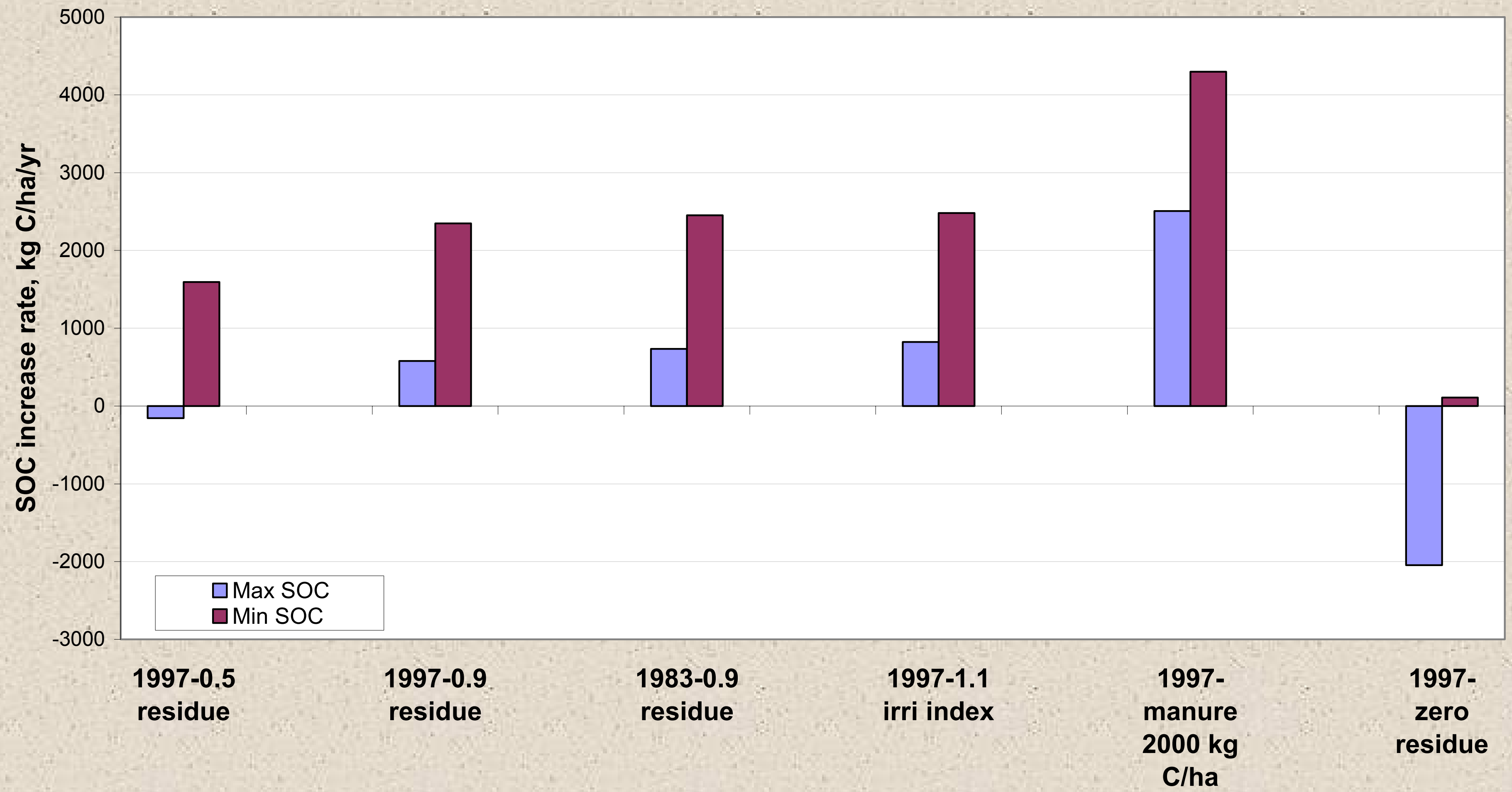
Baseline Results:

- Baseline: 1997 climate with 50% residue incorporation
- Carbon Sequestration: -0.6 to 6.1 Tg
  (-22.4 to 2.2 MMT CO_2 eq.)
- N_2O Emissions: 0.21 to 0.51 Tg N
  (10.0 to 24.7 MMT CO_2 eq)
- CH_4 Emissions: 1.1 to 1.7 MMT CO_2 eq.
- Net GWP: -10.6 to 28.0 MMT CO_2 eq.

C Sequestration Rates by Scenario



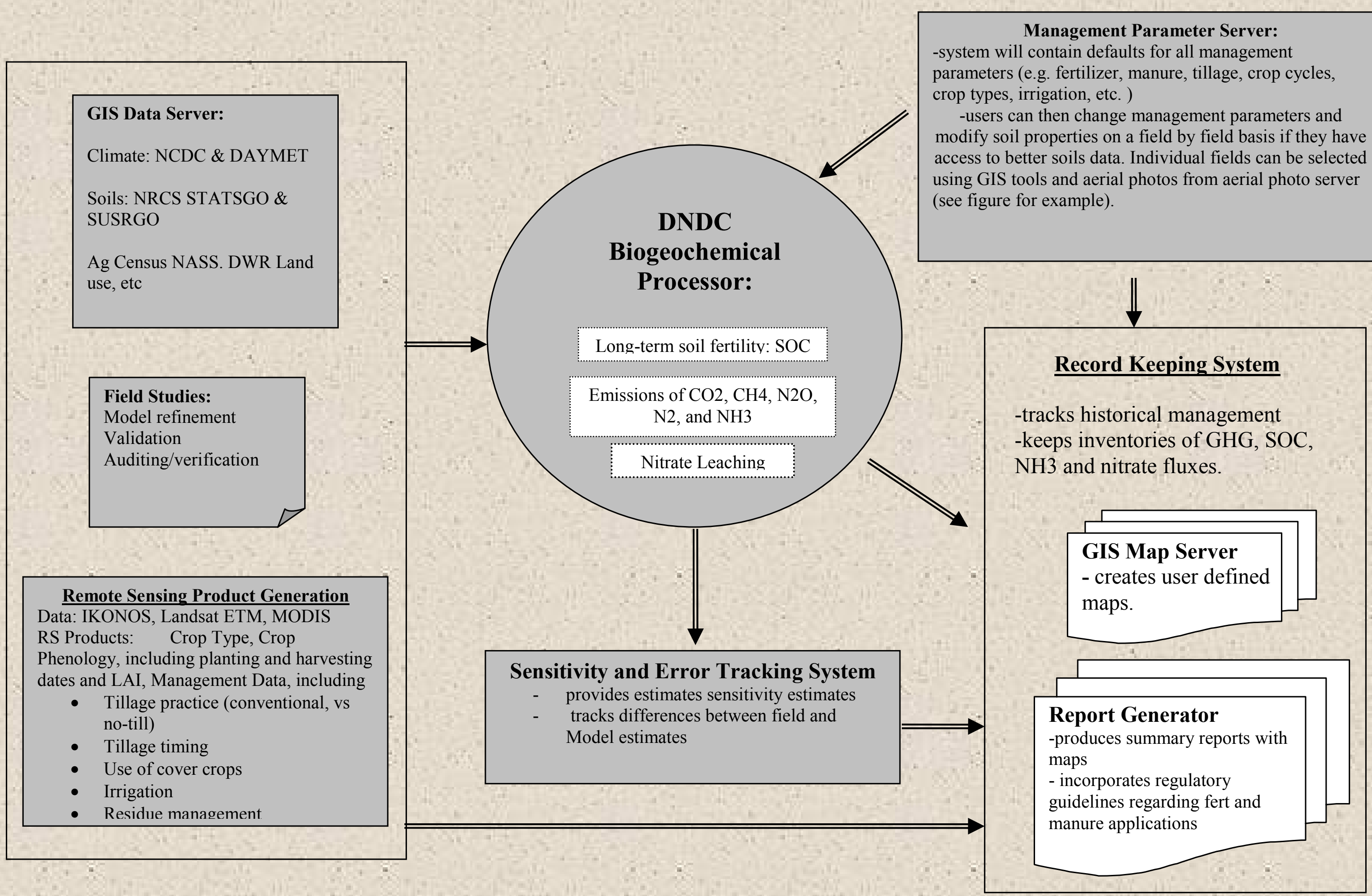
Impact of Scenarios

- **Climate impact**: Shifting climate data from 1997 to 1983 resulted in a slight increase in total carbon sequestration for California, likely due to slightly cooler and wetter weather resulting in lower decomposition rates.
- **Impact of residue incorporation:** Increasing aboveground litter residue incorporation from 50% to 90% could significantly increased C sequestration rates by about 700 kg C/ha/yr. With higher residue incorporation conditions, California agricultural soils could be a significant sink (2.2 to 9.0 Tg) of carbon. On the other hand, if all aboveground residue is removed from the field, then agricultural soils could be a small 0.4 Tg sink to a large 7.8 Tg source of carbon.
- **Impact of manure amendment:** Increasing manure application from 0 to 2000 kg C/ha with 90% residue incorporation substantially elevated C sequestration in California agricultural lands to 9.6–16.5 Tg C.
- **Over-irrigation impact:** Increasing the irrigation index from 1.0 to 1.1 slightly increased C sequestration, most likely due to the decreased decomposition rates under higher soil moisture conditions.

Recommendations

- **Management Data Collection**. Data collection should be conducted to obtain a better spatial representation of management practices to account for regional and cropping system differences. The critical data needs include ***residue management*** and ***manure amendment***. These data are required to more accurately estimate soil C inputs. Residue management practices have changed significantly in response to regulatory actions, (Rice Straw Burning Reduction Act of 1991 and SB 705 goal to phase out open field burning of agricultural waste).
- **GIS Soil Databases*.*** Soil properties, in particular SOC content, have a significant influence on carbon dynamics and trace gas emissions. Use of the improved spatial and thematic resolution SUSRGO data will improve model estimates of carbon dynamics and GHG emissions.
- **Rigorous model validation*.*** Although DNDC has been validated across a wide range of agroecosystems worldwide additional validation is important to quantify how well the model performs in simulating carbon dynamics, N2O and CH4 emissions for the wide range in Californian agroecosystems.
- **Evaluation of additional management scenarios**. Several additional scenarios should be considered for studying mitigation alternatives, including for example:
  - no-till, conservation tillage, and conventional tillage;
  - optimized fertilizer application rates; and
  - use of cover crops.

Linking Science to Policy: Role for Decision Support Systems



Thank You!

Acknowledgments: Scoping analysis was supported by Kearney Foundation, CDFA and California Energy Commission.